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(54) MACHINE TOOL

(71) We, THE CINCINNATI MILLING MACHINE COMPANY, a corporation of the State of Ohio, of Cincinnati, Ohio, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to a machine tool and, more particularly, to apparatus using a plurality of light beam paths in side-by-side relationship for the determination of tool position.

In the operation of machine tools and, particularly, those that have tool changers and have numerical control, there are a number of practical problems. The most important of these problems has to do with the location of the point of the tool. In a tool changer situation, each successive tool is provided with its own tool holder which fits snugly in a socket in the machine tool spindle; this locates the tool holder very accurately along the spindle axis. The operative point or edge of the tool may vary, however, in its position along the axis. This is because the tool may have become worn, or have been sharpened or have shifted within the tool holder since the machine was set up and the position of the tool point recorded on the tape control. Also, thermal growth of the tool is a problem. Without a definite known starting position for each tool, tape control with accuracy is impossible. These and other difficulties experienced with the prior art devices have been obviated in a novel manner by the present invention.

The present invention consists in a machine tool, comprising

(a) a base on which are mounted a tool and a workhead,

(b) feed means producing a relative movement between the tool and the workhead along a feed path,

(c) a generator emitting a beam of constant frequency light,

(d) means causing the beam to pass in a plurality of beam paths in side-by-side relationship all lying in a plane extending at a right angle to the said feed path and at slight angles to one another, each beam path having a discrete width and the plurality of beam paths defining an area substantially larger than the area subtended by the beam itself, and

(e) a photocell receiver on which the light impinges and acting, when the tool enters the plane and interrupts the beam, to establish a reference point in the said feed path.

The character of the invention, however, may be best understood by reference to structural forms of the invention as illustrated, by way of example, in the accompanying drawings, in which:

Fig. 1 is a plan view of a machine tool embodying the principles of the present invention;

Fig. 2 is a vertical sectional view of the invention taken on the line II-II of Fig. 1;

Fig. 3 is a vertical elevational view of a modified form of the invention;

Fig. 4 is an enlarged plan view of a portion of the machine tool;

Fig. 5 is a perspective view of another machine tool making use of the invention but with the workhead removed; and

Fig. 6 is an enlarged perspective view of a portion of the machine tool shown in Fig. 5.

Referring first to Fig. 1, wherein are best shown the general features of the invention, the machine tool, indicated generally by the reference numeral 10, is shown as having an elongated base 11 on which is mounted a tool slide 12. Means is provided to permit the tool slide to move laterally of the base for cross-feed motion during a machining cycle. Fastened to the upper surface

of the tool slide is a tool holder 13 on which is mounted a single-point tool 14.

Also mounted on the base 11 is a work slide 15 having a rotatable spindle 16 on which is mounted a workpiece 17 having a surface to be generated by the tool 14. The spindle is carried in a workhead 18 and is driven by a motor 19 also mounted on the work slide. Means is provided to bring about movement of the work slide 15 longitudinally of the base and in the direction of the axis of the spindle.

Extending laterally of one side of the work slide 15 is an arm 21 which carries a light beam generator 22. Extending outwardly from the other side of the work slide 15 is an arm 23 carrying a receiver 24. The light leaving the generator 22 and passing to the receiver 24 forms a plurality of light beams 25 which lie in a plane extending at a right angle to the axis of the spindle 16.

In Fig. 2 it can be seen that the light beam generator 22 produces a beam 26 of constant frequency light, commonly known as a laser beam. The beam is first directed through a shield 27 and passes to a mirror 28 which lies adjacent the receiver 24 and which reflects the beam back toward the generator. The beam impinges on a mirror 29 which, in turn, directs it back. The mirrors are hingedly mounted for angular adjustment about axes parallel to the spindle axis and, by being positioned with their reflecting surfaces slightly out of parallel, the beam is reflected back and forth in a zig-zag configuration to define a plane 25 of light beams. Finally, the beam is reflected back from the mirror 29 and passes below the lower edge of the mirror 28 to the receiver 24 which contains a photocell 31. The photocell is connected in the usual way to a relay in such a way that failure of light to impinge on it causes a signal to pass to the control for the machine tool and indicate to the control that the tool has reached the plane 25. The vertical and lateral location of the tool 14 is immaterial, since the sheet of light is selected to be broad enough to cover all possible positions of the tool.

Fig. 3 shows a modification of the means for converting the light beam to a fan-like sheet of light beams. A laser generator 22*a* produces a beam 26*a* which is directed to a mirror 32. The mirror is mounted for oscillation about an axis 33 which is parallel to the spindle axis, so that the light is directed into a fan-like sheet 34 after passing through a slot in a shield 35. The beam impinges on a mirror 36 which is provided with a mathematically formed surface such as a paraboloid and which concentrates the beams on a lens 37 which directs it into a receiver or photocell 38. When the beam is interrupted at any time in its swinging movement, the photocell passes this fact to the machine tool control.

Fig. 4 shows, somewhat schematically, the manner in which a tool tip 39 penetrates a sheet 41 of light made up of a plurality of slot-shaped beams 42, 43 and 44. In a practical embodiment of the invention, the tool tip has a radius of .0025", the beams are 0.0005" thick and 0.003" wide, while the edges of the beams are 0.0005" apart. When the tool tip has intruded into the sheet 41 far enough to reduce the cross-section of one of the beams by 20%, the detector will react. The intrusion of the tool tip between two adjacent beams results in the same reduction in the output beam as if only one beam were involved; this is due to the fact that in reflecting from the mirrors, the sides of the beams are reversed.

Some of the advantages of the invention are as follows:

1. It eliminates the requirement to preset the effective length of cutting tools in tool holders.

2. It eliminates the machine-involved time to compensate for randomly set tool lengths.

3. It provides greater accuracy in Z-axis feeding: i.e., feeding of the tool in the direction of the spindle axis

(a) eliminates the build-up in tolerances resulting from pre-setting inaccuracy and tool holder-to-spindle bottoming variation.

(b) Automatically compensates for thermally-induced dimensional changes in the machine tool.

(c) Automatically compensates for orthogonal inaccuracies in the machine tool (particularly significant on large machines such as travelling column configuration in which the spindle nose position is affected by the straightness of the ways and by the co-planar relationship of the two-way surfaces).

4. It permits an entirely different approach to be made to tool holder and spindle nose design of a machine tool as shown in Fig. 5, since accurate depth registry of tool holder in the spindle is no longer a requirement. For example, this invention will permit the use of tapered shanks with the associated improvement in rigidity and control of runout.

A review of the state of the art before the present invention will be of interest.

There are presently two widely used methods of controlling the position of the tip of cutting tools in relation to Z-axis measurements in position-servo controlled machines. One method is to pre-set the tool in a tool holder in a controlled depth relationship to a shoulder on the tool holder that will register against a mating surface on the nose of the spindle. With this ar-

rangement, the position of the cutting edge becomes known in relationship to the spindle nose which, in turn, is in a controlled relationship to the measuring scale. This system has the following major deficiencies:

1. It is expensive in that rather high labour content is involved in setting tool tips to the accuracy required for most applications. This is a particularly time-consuming job when collets are used (as they frequently are) to grip the cutting tool shank or the shank of the cutting tool holder adapter. As the collet is tightened, it has the characteristic of bringing about an axial movement to the shaft that it is gripping. Thus, if the shaft was in its correct position before the collet was tightened, after tightening, it is no longer there. It is not uncommon for the tool pre-setter to tighten and loosen the collet three or four times before he ends up with the collet tight and the tool tip where it is desired.

2. As cutting tools are sharpened and their length changes, it is often necessary to use length compensators ("stub alongs") that add still another mechanical element which tends to increase the runout of the tool and the cost of pre-setting.

3. The pre-setting method requires that the programmer determines whether he wants a standard tool offset or a special, and transmit this requirement to the tool pre-setting station. This invention simplifies the programmers task, since he makes all Z-axis cutting tool instructions using the measuring station of the machine established by the "sheet of light" as his point of departure.

4. The pre-setting method complicates the design of tool holders and of the spindle nose and increases the cost of both. It also denies the use of taper shank tool holders wherever high accuracy of depth control is a requirement and adjustment on the machine is not desired. In some machine tool holder designs, the tool changing system is also complicated by the pre-setting principle. For example, tool holders using an end adjustment stud have a variable depth penetration in the spindle nose depending upon the setting of this stud which is dimensionally related to the tip of the cutter. With this arrangement, the tool loading mechanism must have the ability to seek the pickup groove on the tool shank since its position is not fixed from tool to tool. This increases the cost and complexity of the tool pickup system and also increases the time required for tool change.

The other method of relating the tool tip to the Z-axis measuring system is to mount the cutting tools in tool holders without regard to where the tip of the cutter is. Then on the machine, the operator performs a series of steps involving positioning the tip of the cutter in a controlled relationship to the part or the work support surface and, in effect, recording the position of the axis while the cutting tip is so oriented. The disadvantages of this system are :

1. It reduces the productivity of the man/machine system by requiring these time-consuming operations on the machine.

2. It increases the complexity of the machine tool and control system by the addition of those controls, displays and memory circuits that are required.

There are two special methods that have been applied to date of automatically accommodating randomly set tools, but they too have major disadvantages. One way is to mount in the spindle a means of detecting when the tool strikes the work and initiates the Z-axis measurment at that point. Some of the disadvantages in this approach are:

1. Frequently the criteria for depth of penetration of the tool in the part is not the surface of the part the tool first encounters.

2. The velocity with which the tool can approach the work is considerably lower than that which may be used satisfactorily with this invention.

3. The principle used here is not compatible with horizontal spindle machines due to greatly more complicated friction problems. This is a major drawback since most tool changing systems are associated with the ability to rotate the workpiece which, in turn, dictates a horizontal spindle configuration.

The other system uses a beam of light to detect, in a very gross way (within a 1/4"), where the tip of the tool is. This signal is used to slow down the rapid advance a safe distance before the tool would strike the work. The actual moment the tool struck the work was detected by vibration pickup mounted on the fixture. The vibration pickup, in turn, would activate the depth measuring circuit. This system has been in actual use for many years; however, it will probably not be used extensively as it has the following major deficiencies:

1. No vibration pickup unit has yet been found that could be mounted in a single place on the fixture and reliably respond to all the different tool engagements on the part. This is currently compensated for by the operator striking the fixture with a hammer if the vibration pickup fails to respond.

2. Machine time is wasted with the requirement that the tool approach through a safe distance at a very slow rate prior to tool engagement on the part.

3. The fact again that the criteria for depth penetration is frequently not the surface of the part first contacted by the cutter.

In general, the essential principle of this

invention is to use a beam of light of exteremely small diameter (in the order of .0002″ to .0005″) to form the equivalent of a sheet of light that the tool tip must pass through. The beam may be generated by a laser or a more conventional light source. Two methods may be used to convert the beam into what in effect will be a sheet of light:

1. Use two surface reflecting mirrors set slightly out of parallel one to the other and cause a single beam to be reflected back and forth so that in the region that the tool must pass through the beams are closely spaced.

2. Cause a single beam to be reflected from a rotating or oscillating reflective surface so that the beam sweeps the area where the tool tip must pass. In the first method, the termination of the light beam after a series of reflections from the mirrors will be an optical lens system which will spread the beam and cause it to impinge on a light detecting source such as a photo cell. In the second method, the oscillating beam of light will strike a parabolic reflecting surface which will cause the beam in any of its sweep positions to fall upon a common optical lens system which will spread the beam and cause it to impinge again upon a light detecting device.

The first method, using two surface reflecting mirrors, as shown in Fig. 5 will be suitable for those machine applications where the most advanced surface of the cutting tool will be on the spindle axis or in a controlled angular orientation around the spindle axis. For example, a single cutter boring tool could be detected by this system if the tip of the tool was always in a controlled angular orientation at the time it passed through the "sheet of light". The same is true of fly cutters, trepanning tools, and multi-toothed milling cutters. This first principle can also be used without angular orientation control of the cutting tool by rotating the spindle at high speed and causing the tool tip to pass through the sheet of light at a reduced lateral velocity. This latter method is not recommended for most applications since it has the disadvantage of increasing the time required for the tool to reach the work. One advantage of this invention is the provision of a means of performing this measurement while the tool is approaching the work high rates which may be as high as 200″ per minute. A very simple and highly effective Z-axis measuring system can be employed with this tool tip finding system. A pulse generating transducer which may have a resolution as fine as .0001″ would generate pulses as the Z-axis advanced from the tool loading position. This pulse train would be ignored until the tool tip intruded upon the "sheet of light". At the instant the tool tip interrupts the beam, counting of the transducer generated pulses would begin. Z-axis movements would be programmed from this same measuring station. (In effect $Z = O$ is the "sheet of light"). In the case of large machines such as travelling column, the fact that the "sheet of light" is an absolutely flat plane would greatly improve the overall accuracy of the machine. The present method of measuring Z-axis movements is within the column itself and is not compensatable for variations in the position of the column as it travels down its way system.

For the successful application of this invention, it is imperative that the tip of the cutter be clean and dry at the time it penetrates the "sheet of light". In the case of manually loaded tools operating under Z-axis position servo, we can rely on the operator to take steps to assure that the tool tip is clean and dry. In the case of automatic tool changing machines, it is necessary to add a tool tip cleaning station to the machine. The tip of the cutting tools are presumed to be clean and dry when they are first placed in the tool storage matrix of the machine tool. This is a valid assumption since, obviously, the cutting edge must be inspected for sharpness, and we can reasonably count on their being clean without imposing any new burden on anyone. Each time these tools are loaded into the spindle and caused to advance toward the "sheet of light", the height setting of a tool tip cleaning unit will move at the same speed and through the same distance as the tip of the tool. When the tool tip interrupts the beam of light, the cleaning unit will lock itself in the position it was at the instant the signal is received from the light detecting source. Thus, as each tool is caused to approach the work, the cleaning unit moves a corresponding distance and stops when it is properly positioned to accommodate the cleaning of that particular tool. As tools are unloaded from the spindle and on their way back to storage, the cleaning head consisting of a rotating brush and an air blast, would cleanse the tip. Thus, the tips of all cutting tools in the storage matrix are kept clean, and can, therefore, be accurately measured as they pass through the "sheet of light". The details of the design of the cleaning station will vary with each machine depending primarily on the type of cutting tools used by the machine and the maximum diameters of such tools. A rotating soft wire brush in which the tool tip would penetrate perhaps 1/8″ would appear to be a very adequate system for assuring that there are no chips remaining on the tip of the cutter. After brushing, a sheet of air wide enough to encompass the largest diameter tool would be passed

through as the cutter moved on into the storage matrix.

The majority of cutting tools have a forward face geometry that is compatible with this measuring system, i.e., most forward element of the cutter is the surface that measurements should be made from. There are exceptions, however, some types of boring bars and virtually all piloted tools. In these cases, the non-cutting edge would enter the "sheet of light" before the cutting edge. A practical solution to this problem would be to standardize the length of pilot pins used on spot facers and other cutters. The programmer would define Z-travel from the tip of the pin rather than the cutting edge. In the case of the boring bar in which the cutting edge does not precede the bar body, the same principle would apply. The programmer would call for bar travel distance as measured from the tip of the bar rather than the tip of the cutting edge. In the case of boring bars, an easy way to achieve a standardized dimension between the cutting edge and the tip of the bar would be to have a threaded stud in the end of the bar, the tip of which could be adjusted to be the standard distance forward of the cutting edge.

The choice between surface reflecting mirrors or the oscillating beam principle will depend upon a good many factors including:

1. Type and configuration of machine
2. Accuracy with which depth must be controlled
3. Size and types of cutting tools to be used
4. Cost (in terms of lost productivity) of a slower rate of travel through the measuring station

Generally speaking, the surface reflecting mirror principle should be applied wherever its performance is compatible with the overall system requirements.

The following discussion will establish some of the parameters surrounding the surface reflecting mirror approach. By using coherent light generated by a laser, the diameter of the light beam can be as small as a few millionths of an inch. Suppose we wish to apply the surface reflecting principle to an application in which the permissible error in tool tip reading was not to exceed .001″. For such an application, we might elect to use the light beam of .003″ by .0005″ in conjunction with a light detecting system that would respond to a short term change in the light intensity of 20%. Now suppose we set the angle of the surface reflecting mirrors such that in the area of the spindle axis the distance between the .003″ wide beams was .004″ centre to centre. This should be compatible with the actual radius on even sharp pointed tools and permit detection of well within our permissible tolerance of .001″. Assuming the efficiency of the surface reflecting mirrors to be 95%, then 45 reflections may be made before the input energy has been reduced to 10% of its original value. This reduction in input energy would still permit detection well within the capability of presently available equipment. With the arrangement we have just described, the width of the "sheet of light" in the spindle axis zone would be 0.180″. Factors to be evaluated in optimizing such a design are:

1. Energy concentration in the beam must be such that it does not damage the surface reflecting mirror.

2. Diameter, shape, and spacing of beams to achieve the required measurement accuracy.

3. Light detector and triggering circuit with extreme sensitivity to short term changes in light intensity but relatively insensitive to long term drifts.

In applying the oscillating beam principle, again application variables will modify the system design. The initial primary considerations will be the accuracy with which measurements must be made and the maximum diameter of tools to be detected. These considerations will establish the beam diameter and the arc to be encompassed by the sweep of the beam. The configuration and placement of the light collecting reflective surface and the light detector will depend primarily on the machine configuration. For example, on a column type vertical spindle machine, the light source and detector could be mounted solidly on the column and the reflecting surface on the operator's side of the machine. An alternative to this would be to have the light source floor mounted at one end of the machine and the reflecting surface and light detector on the other end of the machine. The means used to cause the beam to sweep will depend upon the size of the arc and the cycle rate at which the sweep must occur which would be related to the rapid traverse rate of the machine and the accuracy with which measurements must be made. For many applications a simple 60 cycle vibrating surface reflecting mirror would be quite adequate. If higher sweep rates are required than 60 cycles per second, a rotating reflecting surface would be a simple and adequate solution. In either case, the beam striking the oscillating or rotating surface could be quite large, since the reflected beam would pass through a slit of the required size to control the beam thickness and the position of the plane generated by the sweep of the beam.

In Figs. 5 and 6 are shown a practical embodiment of the invention in a numerically-controlled tool changer machine tool

44. The machine tool has a base 45 having horizontal ways 46. A column 47 is mounted on the ways for X-axis motion under the impetus of a motor 48. The front vertical face of the column is provided with Y-axis ways 49 on which a saddle 51 is mounted for sliding motion under the control of a motor 52. The saddle has horizontal ways 53 and 54 for holding a spindle head 55. The spindle 56 extends through the head and is provided with a tool 57. A spindle drive motor 58 is mounted at the rear of the head and a tool storage matrix 59 is mounted on its side. A tool changer 61 is mounted on the head for moving tools from the tool storage matrix 59 to the spindle 56 and back.

A bracket 62 is bolted to the saddle 51 and on its free end is mounted a light beam generator 63. Similarly, a bracket 64 is bolted to the saddle 51 and carries on its free end a light beam receiver 65.

In Fig. 6, it can be seen that the generator 63 is provided with an outer tubular housing 66 in which are mounted a light beam emitter 67, an optical mask 68 with a control aperture, an optical member 69 with a flat mirror surface, a shutter 71, and a slotted mask 72. The receiver 65 is similarly constructed, carries a detector instead of a light beam emitter.

Both the generator and the receiver are provided with dry pressure air which escapes through the mask and denies entrance to foreign matter. The generator and receiver move with the saddle 51 along the X-axis and the Y-axis, but do not participate in the Z-axis motion with the spindle. They, therefore, operate to indicate the intrusion of the tool 57 into the plane of the light beam extending between them when the spindle is moved along the Z-axis. This arrangement can be used, for instance, to indicate a zero position of the end of the tool from which the numerical controls can set their dimensions.

It is not, however, desired to confine the invention to the exact form herein shown and described, but it is desired to include all such as properly come within the scope claimed.

WHAT WE CLAIM IS:—

1. A machine tool, comprising
   (a) a base on which are mounted a tool and a workhead,
   (b) feed means producing a relative movement between the tool and the workhead along a feed path,
   (c) a generator emitting a beam of constant-frequency light,
   (d) means causing the beam to pass in a plurality of beam paths in side-by-side relationship all lying in a plane extending at a right angle to the said feed path and at slight angles to one another, each beam path having a discrete width and the plurality of beam paths defining an area substantially larger than the area subtended by the beam itself, and
   (e) a photocell receiver on which the light impinges and acting, when the tool enters the plane and interrupts the beam, to establish a reference point in the said feed path.

2. A machine tool as claimed in Claim 1, wherein the beam paths form a zig-zag configuration.

3. A machine tool as claimed in Claim 1, wherein the beam paths form a fan-like configuration.

4. A machine tool as claimed in Claim 1, 2 or 3, wherein the generator includes a source of a beam of light and a pair of angularly adjustable mirrors arranged only slightly out of parallel to one another and only slightly less than right angles to the beam, so that the beam is reflected back and forth between the mirrors in a zig-zag path forming the plurality of light beam paths in side-by-side relationship.

5. A machine tool as claimed in Claim 1, 2 or 3, wherein the generator includes a source of a beam of light and a mirror mounted for oscillatable movement about an axis extending at a right angle to the path of the beam.

6. A machine tool as claimed in Claim 1, 2 or 3, wherein the generator includes a light beam for producing a beam of constant fixed-frequency light.

7. A machine tool substantially as described with reference to Figures 1, 2 or 4 or Figure 3 or Figures 5 and 6 of the accompanying drawings.

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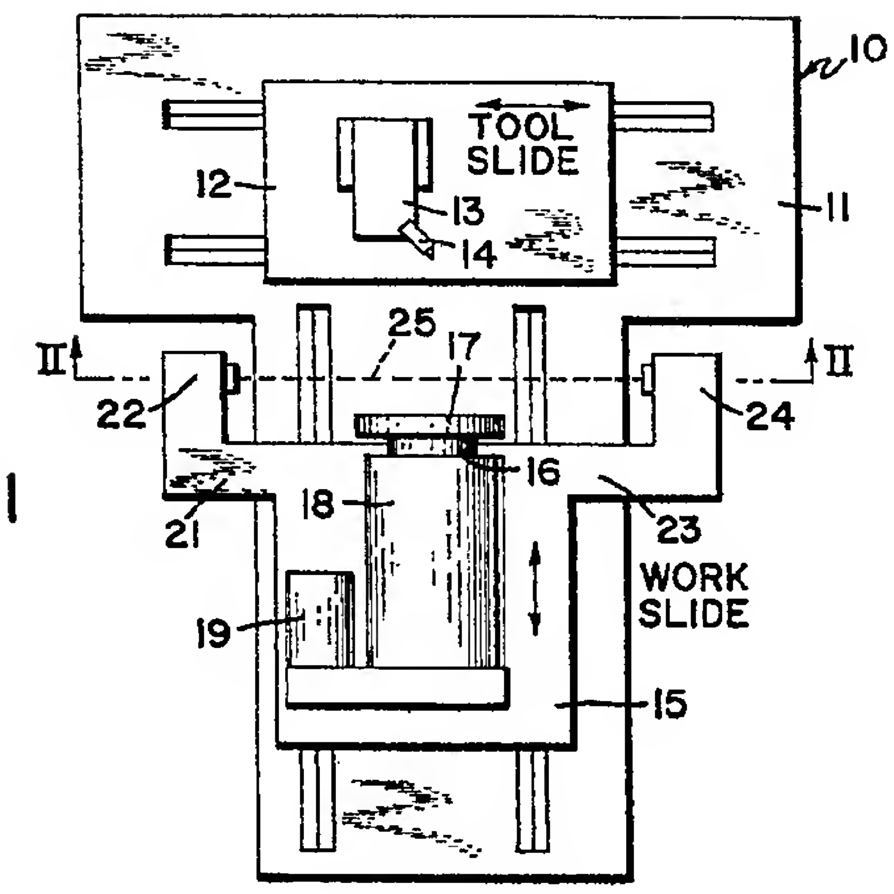

FIG.1

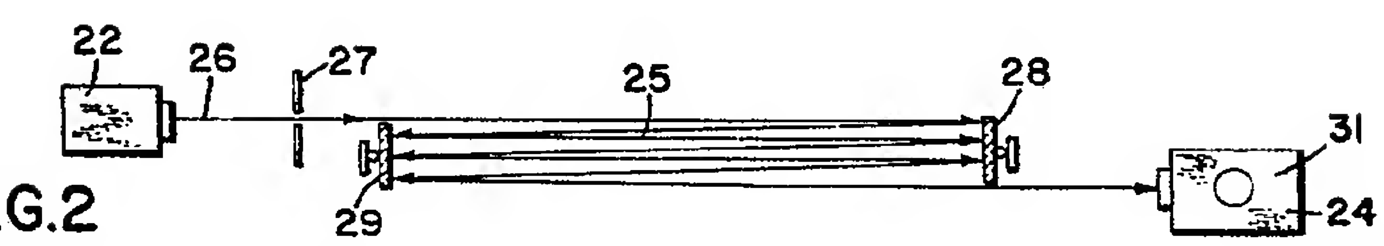

FIG.2

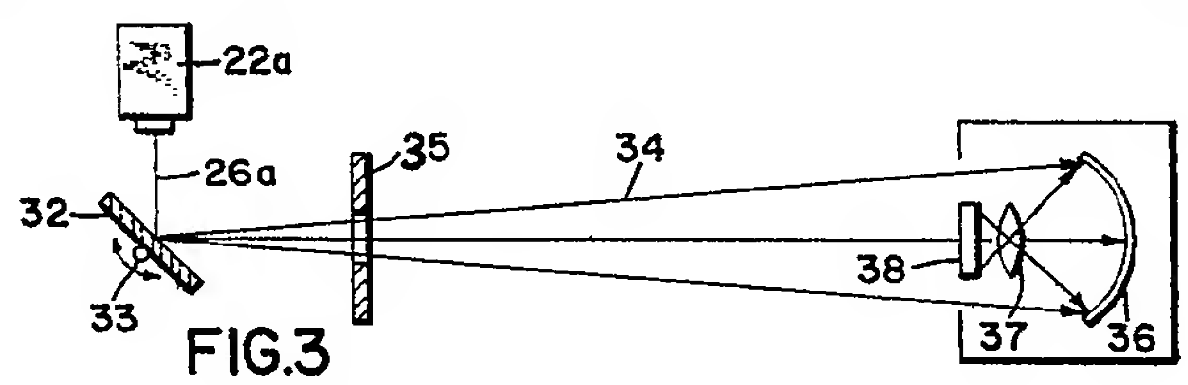

FIG.3

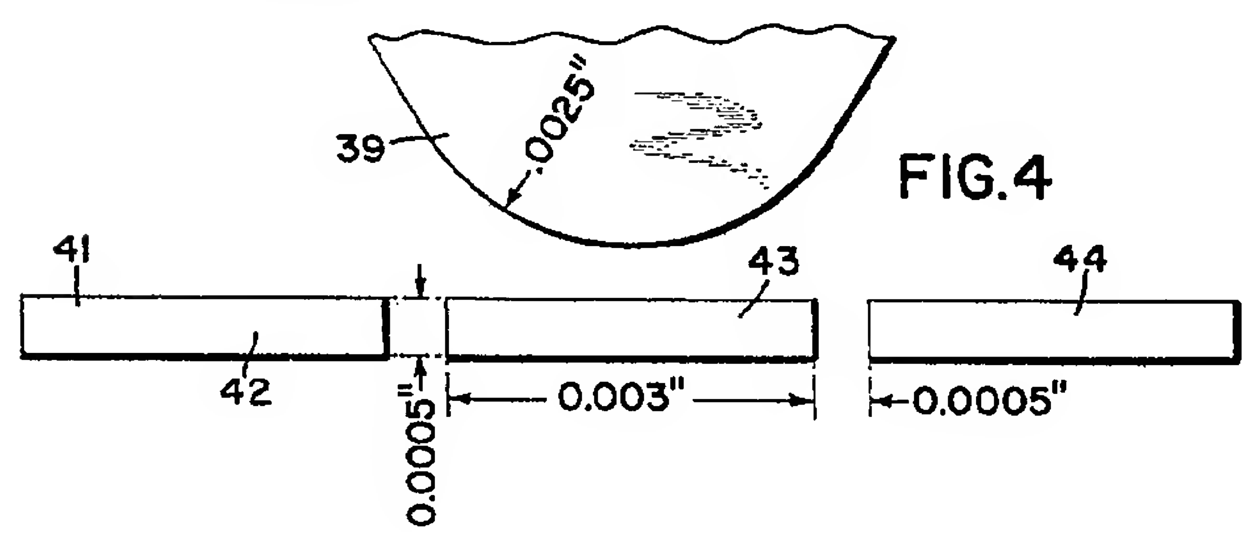

FIG.4

FIG. 6

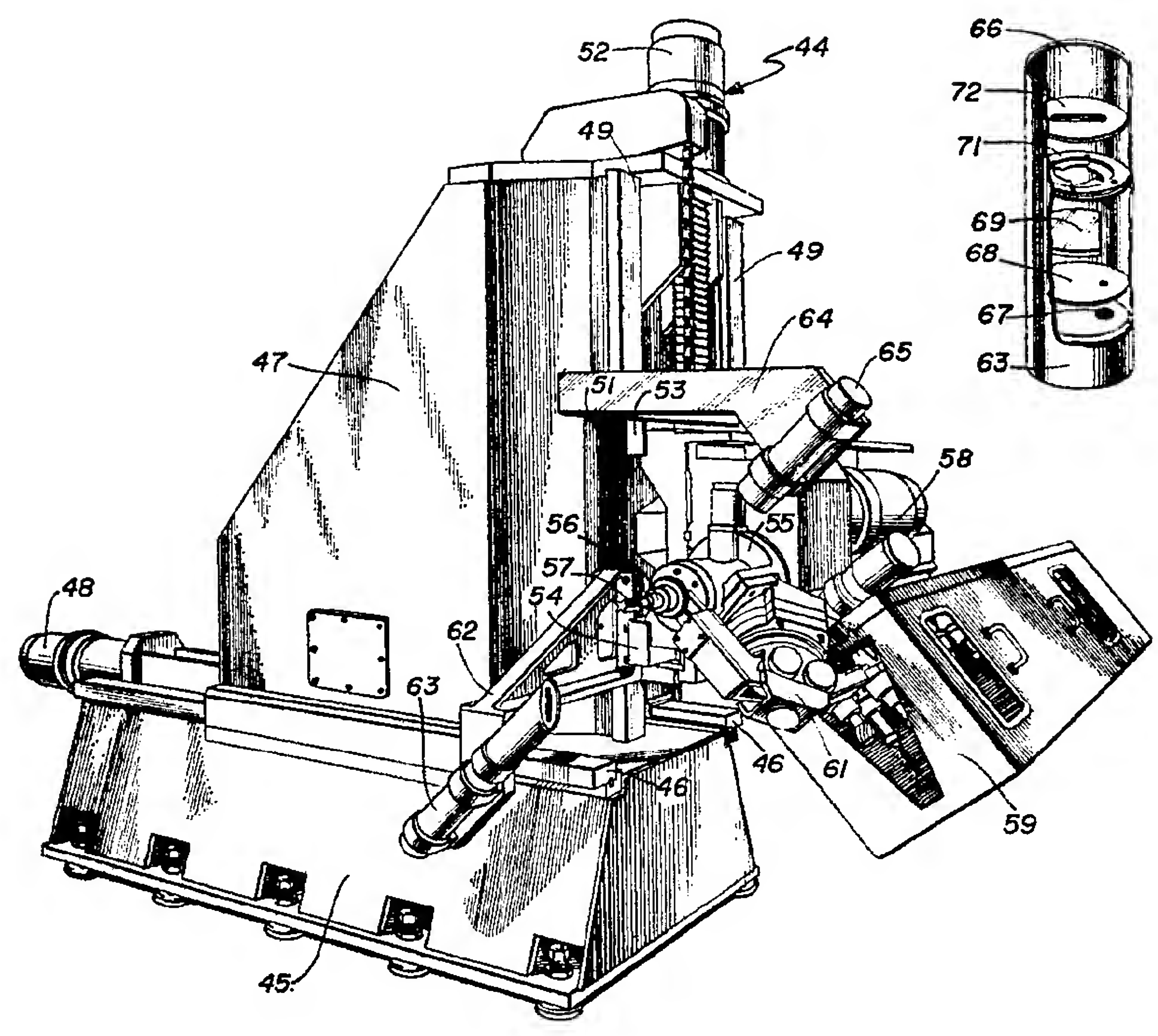
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FIG. 5